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RESEARCH MEMORANDUM

LOW-SPEED INVESTIGATION OF THE EFFECTS OF SINGLE SLOTTED AND DOUBLE SLOTTED FLAPS ON A 47.7° SWEPTBACK-WING - FUSELAGE COMBINATION AT A REYNOLDS NUMBER OF 6.0×10^6

By Ernst F. Mollenberg and Stanley H. Spooner

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September 10, 1951

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LOW-SPEED INVESTIGATION OF THE EFFECTS OF SINGLE SLOTTED AND DOUBLE SLOTTED FLAPS ON A 47.7° SWEPTBACK-WING - FUSELAGE COMBINATION AT A REYNOLDS NUMBER OF 6.0×10^6

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SUMMARY

A low-speed wind-tunnel investigation has been conducted at a Reynolds number of 6.0×10^6 to determine the effects of partial-span single slotted and double slotted flaps at various deflections on the longitudinal aerodynamic characteristics of a 47.7° sweptback-wing - fuselage combination. The wing had an aspect ratio of 5.1, a taper ratio of 0.383, and NACA 64-210 airfoil sections. The maximum wing thickness parallel to the plane of symmetry was 7.5-percent chord.

The maximum increment in maximum lift coefficient $C_{L_{max}}$ due to deflected trailing-edge flaps is less than 0.1 and 0.2 for the single slotted and double slotted flaps, respectively.

The maximum values of $C_{L_{max}}$ obtained with either the single slotted or double slotted flaps on the sweptback-wing - fuselage combination occur at flap deflection angles of from 10° to 25° lower than those indicated by two-dimensional tests. The longitudinal stability is slightly affected by the degree of flap deflection. The largest values of $C_{L_{max}}$ obtained for configurations having stable pitching-moment characteristics at maximum lift are 1.51 and 1.59 for the single and double slotted flaps, respectively, in combination with extended leading-edge flaps.

INTRODUCTION

Much research has been directed toward increasing the maximum lift of sweptback wings and eliminating the longitudinal instability which is often present in the maximum-lift range of these wings. Sufficient data, however, are not available to show the aerodynamic effects of the type of trailing-edge flap, the degree of flap deflection, and the flap position. As part of an investigation to supply this information tests were conducted on a 47.7° sweptback wing - fuselage combination. Reference 1 shows the relationship between the flap effectiveness and the horizontal and vertical position of partial-span single slotted flaps. Reference 2 shows the effectiveness of split-type flaps. The present paper reports the results of tests to determine the longitudinal aerodynamic characteristics with various deflections of both single slotted and double slotted flaps.

The tests were conducted in the Langley 19-foot pressure tunnel at a Reynolds number of 6.0×10^6 and a Mach number of 0.14. The wing had an aspect ratio of 5.1, a taper ratio of 0.383, and NACA 64-210 airfoil sections normal to the 0.286-chord line. The maximum wing thickness parallel to the plane of symmetry was 7.5 percent chord. Several deflections of the single slotted and double slotted flaps were investigated in conjunction with various spans of outboard leading-edge flap. In addition, the effect of flap bracket alinement on the aerodynamic characteristics of the double slotted flap was investigated.

NOTATION

The data are referred to a set of axes coinciding with the wind axes and originating in the plane of symmetry at the quarter-chord point of the mean aerodynamic chord. All coefficients are based upon the dimensions of the basic wing.

C_L lift coefficient (Lift/qS)

$C_{L_{max}}$ maximum lift coefficient

ΔC_L increment in lift coefficient (measured at $\alpha = 8^\circ$)

C_D drag coefficient (Drag/qS)

L/D ratio of lift to drag

C_m pitching-moment coefficient (Pitching moment/$qS\bar{c}$)

q dynamic pressure, pounds per square foot

S wing area, square feet

$\bar{c}$ mean aerodynamic chord, feet $\left(\frac{2}{S}\int_0^{b/2} c^2 dy\right)$

c wing chord, parallel to plane of symmetry, feet

c' wing chord normal to 0.286c line, feet

$b/2$ semispan of wing, normal to plane of symmetry, feet

y spanwise coordinate, normal to plane of symmetry, feet

δ_f trailing-edge-flap deflection, degrees

α angle of attack of root chord, degrees

V_g gliding speed, miles per hour

V_v sinking speed, feet per second

MODEL

The principal dimensions of the model are shown in figure 1. The wing, which was of solid-steel construction, had NACA 64-210 airfoil sections normal to the 0.286-chord line (0.25c'). The maximum wing thickness parallel to the plane of symmetry was 0.075 chord. The sweepback of the 0.286-chord line was 45°, the aspect ratio was 5.1, and the taper ratio was 0.383. The wing was uniformly twisted to produce 1.32° washout at the tip and the dihedral angle was 0°. The fuselage was of circular cross section and had a fineness ratio of 10.2. A midwing arrangement was used with the wing mounted at an angle of incidence of 2° with respect to the fuselage.

The details of the leading-edge flaps are shown in figure 1. The round-nose, extensible, leading-edge flaps had a constant chord and deflection. The outboard end was fixed at station 0.975b/2, and the inboard end was adjustable so that flap spans from 0.375b/2 to 0.525b/2 were available in increments of 0.05b/2.

The details of the trailing-edge flaps are shown in figure 2. The single slotted flaps had a chord of 0.25c' and could be deflected 20°, 30°, or 40°. The double slotted flaps consisted of a 0.075c' vane and a 0.25c' flap which could be deflected 30°, 40°, or 55°. All of the flap arrangements were investigated with the flap brackets alined parallel to the plane of symmetry. In addition, the configuration of double slotted flaps deflected 55° was investigated with brackets mounted normal to the flap hinge line. For zero flap deflection, the flaps were replaced by a solid trailing-edge piece which conformed to the true airfoil section. The chordwise positions of the single slotted flaps were established from the data presented in reference 1. The double slotted flap positions were determined from unpublished two-dimensional data. The flaps extended spanwise from station 0.144b/2 to station 0.450b/2. The outboard end of the flaps was extended only to the 0.45b/2 station since the results presented in reference 3 indicate that leading-edge flaps became ineffective in producing longitudinal stability at maximum lift if the span of the double slotted flaps is much greater than 0.450b/2.

A photograph of the model mounted in the Langley 19-foot pressure tunnel is presented as figure 3.

TESTS

The tests were conducted in the Langley 19-foot pressure tunnel in which the air was compressed to approximately 33 pounds per square inch, absolute. The tests were made at a Reynolds number of 6.0×10^6, based on the mean aerodynamic chord, and a Mach number of 0.14.

The lift, drag, and pitching moments were measured through an angle-of-attack range at zero yaw by a simultaneously recording balance system. The characteristics of the wing-fuselage combination were determined for a range of deflection of the trailing-edge flaps in combination with various spans of the leading-edge flaps.

RESULTS AND DISCUSSION

All data have been reduced to standard nondimensional coefficients and have been corrected for support-tare and interference effects and for air-stream misalinement. Jet-boundary corrections have been applied to the angle of attack and to the drag and pitching-moment coefficients. The jet-boundary induced velocities obtained by means of reference 4 were used to compute these corrections.

Test data are presented in figures 4 to 8 for those configurations considered to be the most promising and for those configurations necessary to show the effects of the flaps. The pertinent lift and pitching-moment characteristics of all of the configurations tested are summarized in tables I, II, and III.

Reference 3 has shown that for the subject wing a leading-edge stall-control device is required for the attainment of longitudinal stability at maximum lift. Most of the discussion is confined, therefore, to the effects of the trailing-edge flaps in combination with extended leading-edge flaps.

Lift Characteristics

The lift characteristics of the wing-fuselage combination equipped with 0.475b/2 leading-edge flaps and with the single and double slotted flaps at various deflections are shown in figure 4. The variation of $C_{L_{max}}$ and ΔC_L with flap deflection is presented in figure 9. For the single slotted flap configuration, $C_{L_{max}}$ increases from 1.44 at $\delta_f = 0^\circ$ to about 1.50 at $\delta_f = 20^\circ$. Further increase in the deflection angle to the maximum angle tested, 40°, results in essentially no additional change in $C_{L_{max}}$. For the double-slotted-flap configuration, $C_{L_{max}}$ increases to a maximum value of 1.59 at $\delta_f = 40^\circ$. Further increase in the deflection angle to the maximum angle tested, 55°, results in a decrease to 1.53. It should be noted that for the other leading-edge-flap spans tested, $C_{L_{max}}$ occurred at $\delta_f = 30^\circ$. The maximum increment in $C_{L_{max}}$ due to deflected trailing-edge flaps amounts to less than 0.1 and 0.2 for the single slotted and the double slotted flaps, respectively. The maximum values of $C_{L_{max}}$ are produced at deflections of the double and single slotted flaps on the subject wing 10° to 25° less than those on the same airfoil in two-dimensional flow, as indicated in reference 5 and in unpublished data.

The lift increment (ΔC_L at $\alpha = 8^\circ$) produced by both flaps increases up to the highest deflection angles tested. The value of ΔC_L produced by the double slotted flaps is slightly larger than that produced by the single slotted flaps. At $\delta_f = 40^\circ$, the value of ΔC_L is 0.46 for the double slotted flaps as compared to 0.40 for the single slotted flaps.

The lift characteristics of the wing-fuselage combination with the trailing-edge flaps deflected 40° and with several spans of leading-edge flap are presented in figure 5. The variation of $C_{L_{max}}$ with leading-edge-flap span is shown in figure 10 for the wing-fuselage combination equipped with the trailing-edge flaps. With both types of trailing-edge flap, $C_{L_{max}}$ increases as the span of the leading-edge flap increases until the maximum value is reached with the inboard end of the flap extending inboard to at least the midsemispan of the wing. Table I indicates that, in general, the largest value of $C_{L_{max}}$ is produced by the longest span of leading-edge flap and that the leading-edge flaps are more effective than the trailing-edge flaps at increasing the $C_{L_{max}}$ of the wing. The increment in lift due to the leading-edge flaps is negligible, as shown in table I.

Pitching-Moment Characteristics

The effects of deflecting of the single slotted and double slotted flaps on the pitching-moment characteristics are shown in figure 6. In the low-lift range, the effects of flaps at small deflections are similar to those produced on unswept wings in that the longitudinal trim changes are proportional to the degree of flap deflection. The trim changes are of relatively small magnitude on this sweptback wing, however, because the inboard location of the flaps places them longitudinally near to the assumed center-of-gravity location ($0.25\bar{c}$).

As indicated by the variations of C_m with C_L, various degrees of instability occur in the lift range just prior to maximum lift. The degree of instability in this range varies slightly with flap deflection angle and is often the least with moderate flap deflections. The lift coefficient at which the initial instability occurs generally increases with increasing flap deflection. At maximum lift, the direction of the break in the moment curve is little affected by the degree of flap deflection. The largest values of $C_{L_{max}}$ obtained for configurations having stable pitching-moment characteristics at maximum lift are 1.51 and 1.59 for the single slotted and double slotted flaps, respectively, in combination with extended leading-edge flaps.

The effects on the pitching-moment characteristics of the various spans of leading-edge flap are shown in figure 7. The addition of certain spans of leading-edge flap results in the pitching-moment curves breaking in a stable direction at or near $C_{L_{max}}$; whereas without leading-edge flaps, the curves break in an unstable direction. With both the single

and double slotted flaps, unstable characteristics are obtained with leading-edge-flap spans in excess of 0.475b/2 and stable characteristics, with spans as short as 0.375b/2, the shortest span tested. The unstable variation of C_m with C_L, which occurs in the lift range just prior to $C_{L_{max}}$, is affected only slightly by the span of the leading-edge flaps.

Drag Characteristics

As a means of evaluating the effects of the trailing-edge flaps on the drag characteristics of the wing-fuselage combination, the L/D ratios are presented in figure 8. The effect of trailing-edge flap deflection on the variation of L/D with C_L, as illustrated by the data obtained for the 0.475b/2 leading-edge-flap deflection, is presented as representative of the results obtained with the other leading-edge-flap spans. A grid of gliding and sinking speeds for an assumed wing loading of 40 pounds per square foot and sea-level conditions is superimposed on the L/D curves of figure 8.

The maximum values of L/D are obtained with the trailing-edge flaps retracted. Deflection and extension of the flaps result in lower maximum values of L/D, but these values occur at higher lift coefficients. Above lift coefficients of 1.0 and 1.2 for the single and double slotted flaps, respectively, the values of L/D become nearly equal as the deflection angle is increased. It appears, then, that the flaps at deflections of the order of 20° or 30° offer the highest values of L/D in the moderate lift range and values of L/D about equal to those obtained with greater flap deflections in the high-lift range.

Effect of Flap-Bracket Alinement

In order to determine the aerodynamic effects, if any, of the alinement of the flap brackets, an investigation was made of brackets mounted normal to the hinge line of the double slotted flaps deflected 55°. The characteristics obtained with the brackets mounted normal to the flap hinge line are compared with those obtained with the brackets mounted parallel to the plane of symmetry in figure 11. In the high-lift range, bracket alinement had little influence on the aerodynamic characteristics of the model. In the lower-lift range, the aerodynamic characteristics obtained with the brackets mounted normal to the hinge line were about the same as those which would be obtained with the brackets mounted parallel to the plane of symmetry but with the flap deflection angle reduced 5°. Strength considerations made it necessary to use brackets relatively larger than would be used on a full-scale airplane, so that full-scale differences in the characteristics due to flap alinement might be somewhat smaller than indicated herein.

CONCLUDING REMARKS

From the results of an investigation in the Langley 19-foot pressure tunnel to determine the effect of deflection of 0.45-semispan single slotted and double slotted flaps on the aerodynamic characteristics of a 47.7° sweptback-wing - fuselage combination, the following remarks may be made:

1. The highest increment in maximum lift coefficient $C_{L_{max}}$ due to deflected trailing-edge flaps amounts to less than 0.1 and 0.2 for the single slotted and double slotted flaps, respectively. The maximum values of $C_{L_{max}}$ obtained with either the single or double slotted flaps on the sweptback-wing - fuselage combination occur at flap deflection angles of from 10° to 25° lower than those indicated by two-dimensional tests.

2. In the lift range just prior to $C_{L_{max}}$, the longitudinal stability of the wing-fuselage combination equipped with leading-edge flaps varies slightly with the trailing-edge-flap deflection. At $C_{L_{max}}$ the stability is unaffected by the degree of flap deflection.

3. The largest values of $C_{L_{max}}$ obtained for configurations having having stable pitching-moment characteristics at maximum lift are 1.51 and 1.59 for the single slotted and double slotted flaps, respectively, in combination with extended leading-edge flaps.

4. Flap deflections of 20° to 30° offer the highest values of lift-drag ratio L/D in the moderate-lift range and, in the high-lift range, values of L/D equal to those obtained with greater flap deflections.

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REFERENCES

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2. Spooner, Stanley H., and Mollenberg, Ernst F.: Low-Speed Investigation of Several Types of Split Flap on a 47.7° Sweptback-Wing - Fuselage Combination of Aspect Ratio 5.1 at a Reynolds Number of 6.0×10^6. NACA RM L51D20, 1951.

3. Salmi, Reino J.: Effects of Leading-Edge Devices and Trailing-Edge Flaps on the Longitudinal Characteristics of Two 47.7° Sweptback Wings of Aspect Ratios 5.1 and 6.0 at a Reynolds Number of 6.0×10^6. NACA RM L50F20, 1950.

4. Eisenstadt, Bertram J.: Boundary-Induced Upwash for Yawed and Swept-Back Wings in Closed Circular Wind Tunnels. NACA TN 1265, 1947.

5. Cahill, Jones F., and Racisz, Stanley F.: Wind-Tunnel Investigation of Seven Thin NACA Airfoil Sections to Determine Optimum Double-Slotted-Flap Configurations. NACA TN 1545, 1948.

TABLE I.- SUMMARY OF THE LIFT CHARACTERISTICS OF THE WING-FUSELAGE COMBINATION WITH VARIOUS FLAP CONFIGURATIONS

Trailing-edge flap		$C_{L_{max}}$					ΔC_L ($\alpha = 8°$)				
		Leading-edge-flap span, b/2									
Type	δ_f	0	0.375	0.425	0.475	0.525	0	0.375	0.425	0.475	0.525
Flaps off	—	1.16	[a]1.36	[a]1.41	1.44	1.45	—	0.01	0.01	0.01	0.01
Single slotted	20	1.25	[a]1.43	[a]1.47	1.50	1.51	.21	.22	.23	.23	.23
	30	1.26	[a]1.45	[a]1.48	1.49	1.52	.31	.31	.31	.31	.31
	40	1.27	[a]1.40	[a]1.46	1.51	1.54	.40	.41	.41	.40	.40
Double slotted	30	1.36	[a]1.47	[a]1.51	1.57	1.62	.34	.36	.37	.37	.36
	40	1.34	1.45	1.51	1.59	1.58	.44	.46	.47	.46	.48
	55	1.32	1.44	1.46	1.53	1.59	.53	.54	.54	.55	.54

[a] Indicates that C_L is increasing at highest α tested.

TABLE II.- SUMMARY OF THE PITCHING-MOMENT CHARACTERISTICS OF THE WING-FUSELAGE COMBINATION EQUIPPED WITH THE SINGLE SLOTTED FLAPS

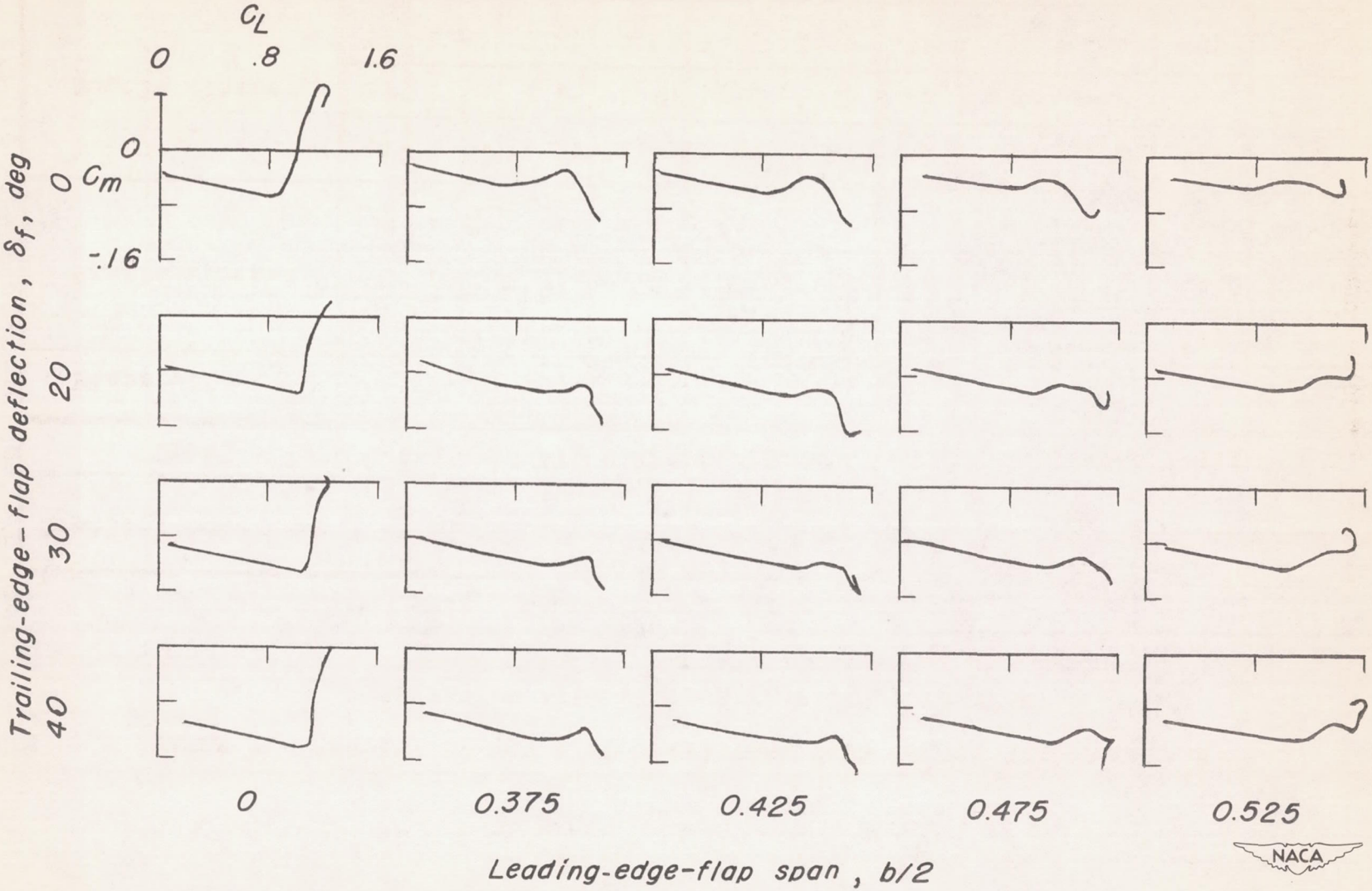
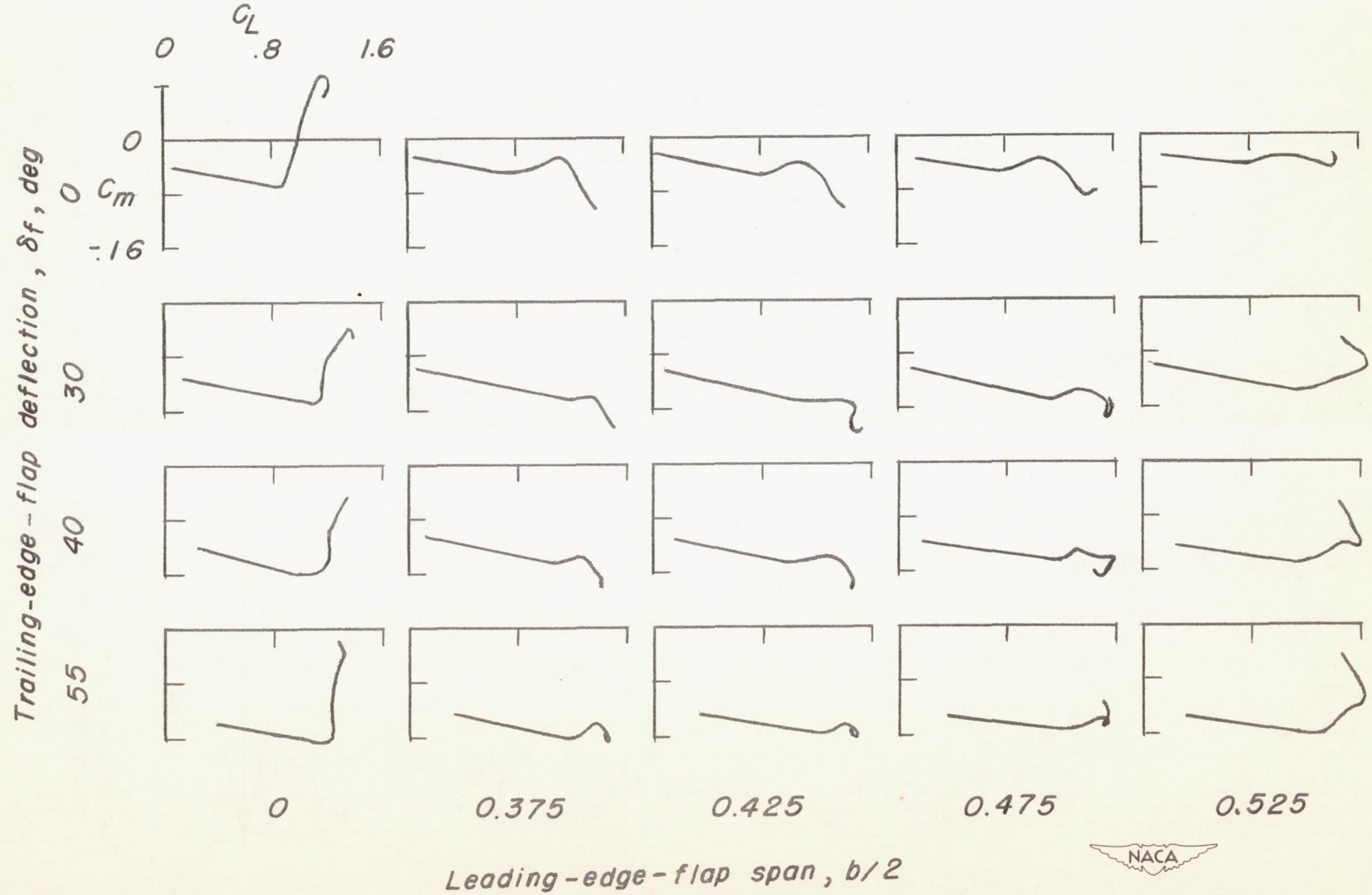


TABLE III.- SUMMARY OF THE PITCHING-MOMENT CHARACTERISTICS OF THE WING-FUSELAGE COMBINATION EQUIPPED WITH THE DOUBLE SLOTTED FLAPS



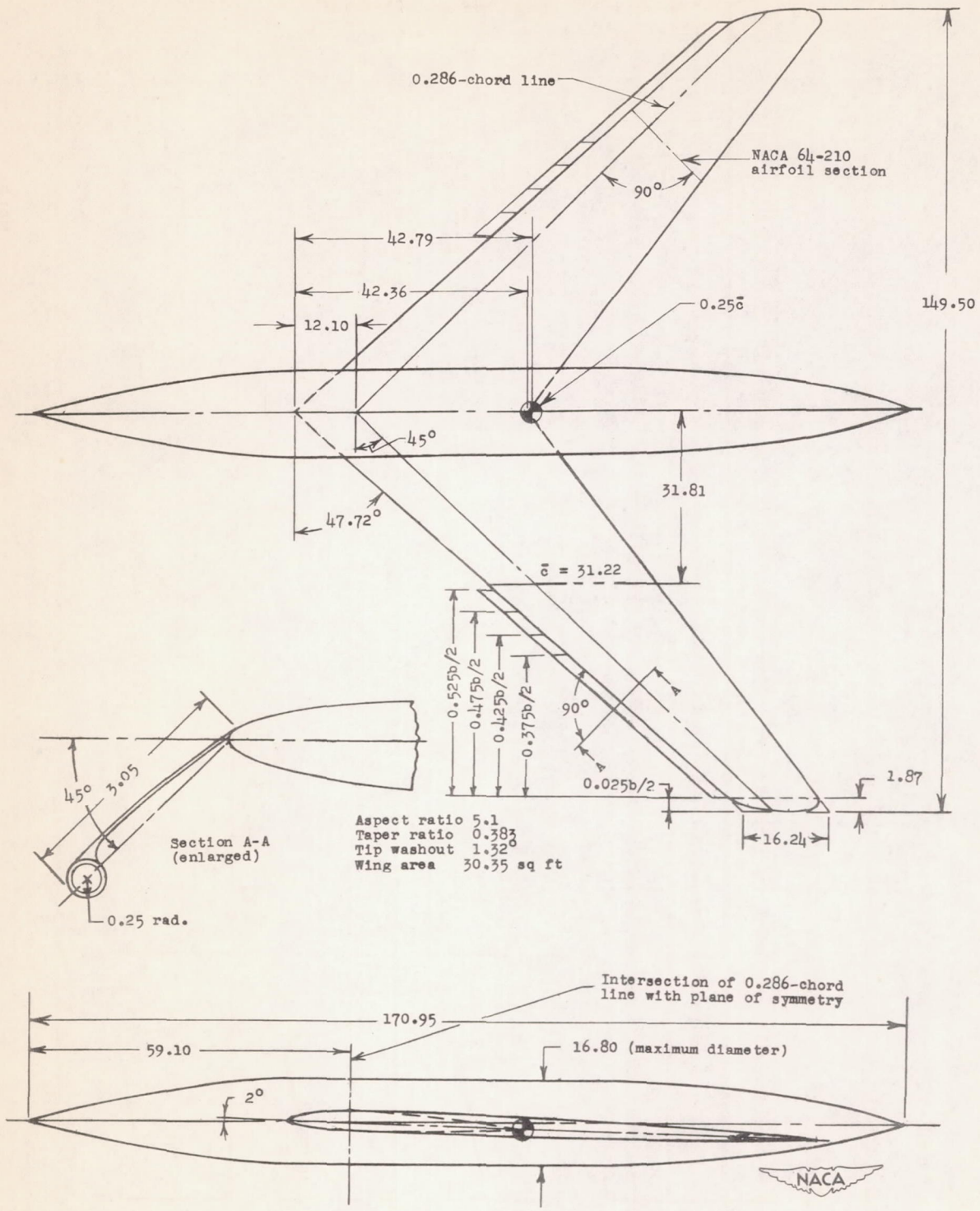
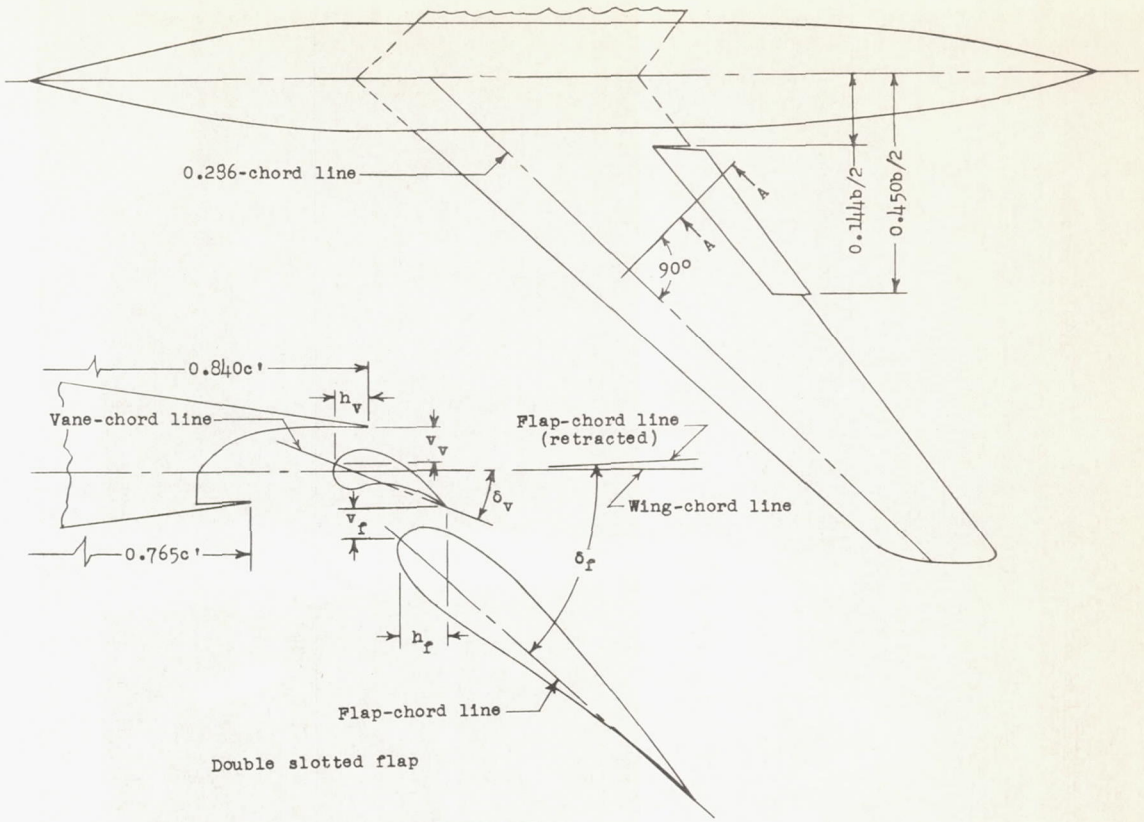


Figure 1.- Geometry of the 47.7° sweptback-wing - fuselage combination and details of the leading-edge flaps. All dimensions are in inches.



	Flap positions, percent c'					
	δ_f	δ_v	h_v	v_v	h_f	v_f
Single-slotted flaps	20°	—	—	—	1.00	2.00
	30°	—	—	—	1.00	2.00
	40°	—	—	—	1.00	1.50
Double-slotted flaps	30°	25°	0.60	1.17	-1.22	4.00
	40°	30°	1.57	1.37	0.82	3.07
	55°	30°	1.23	1.82	2.31	0.56

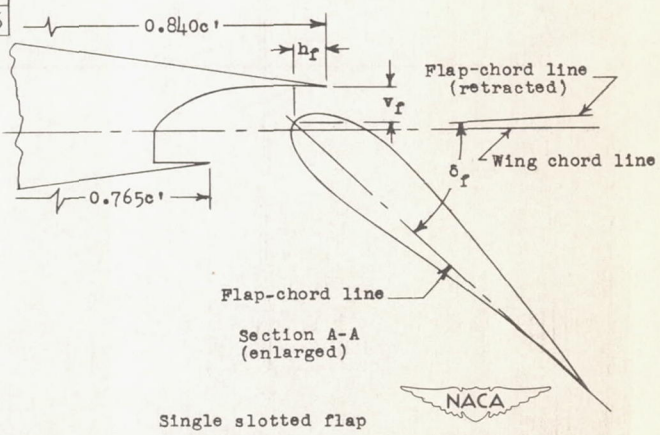


Figure 2.- Details of the single slotted and double slotted flaps. h_v, v_v, h_f, v_f are positive as shown.

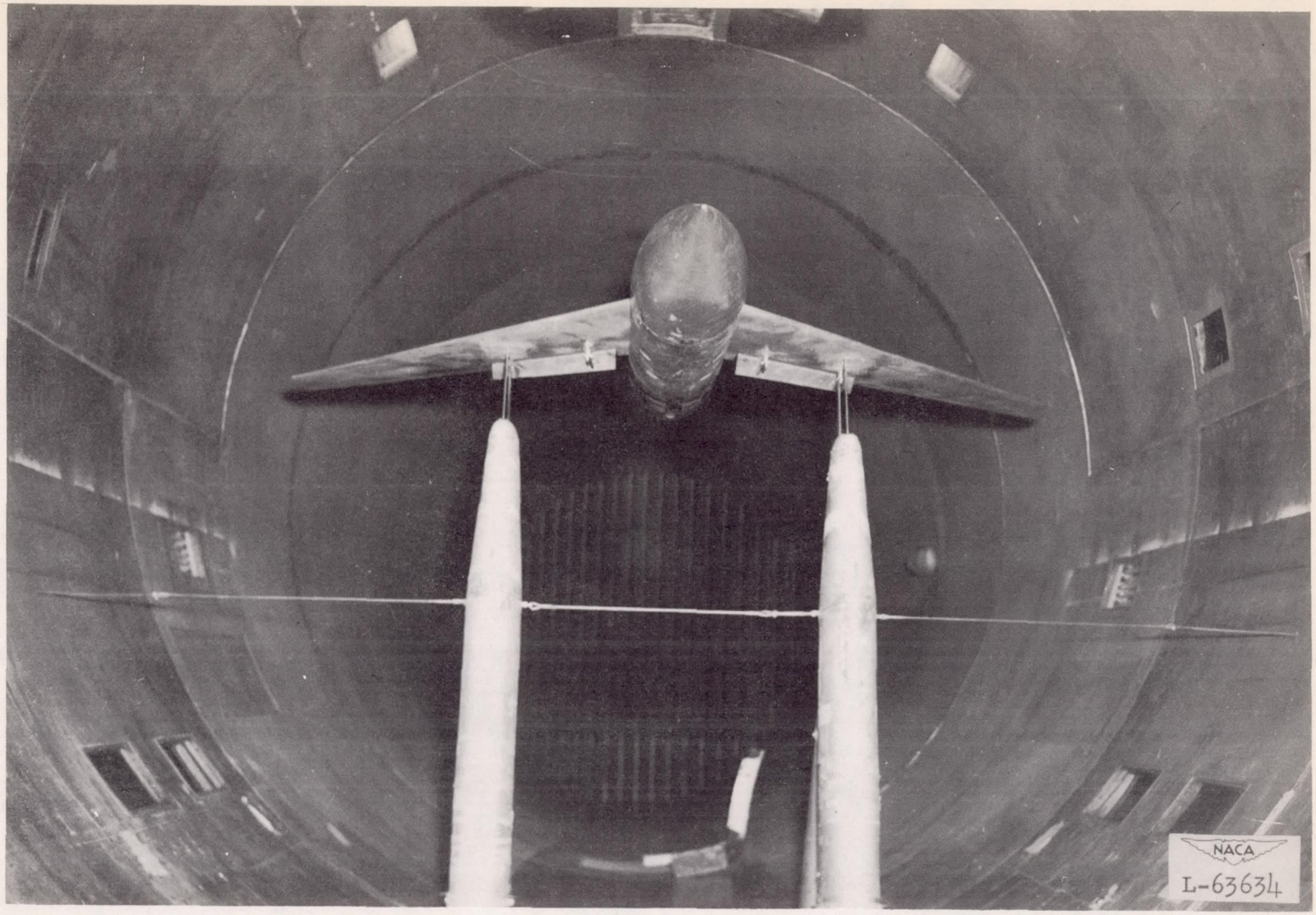
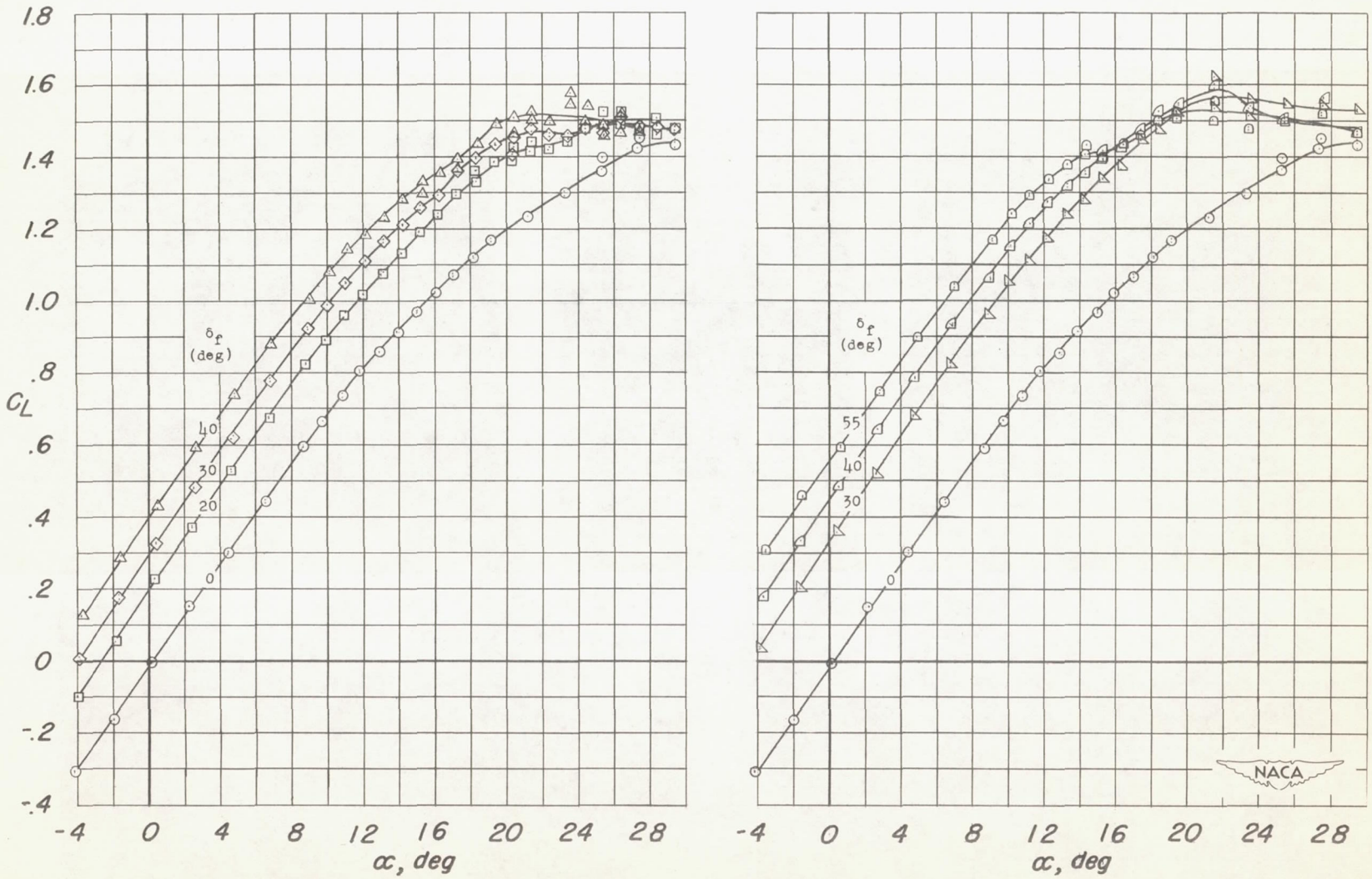


Figure 3.- Wing-fuselage combination equipped with single slotted flaps and mounted in Langley 19-foot pressure tunnel.



(a) Single slotted flaps.

(b) Double slotted flaps.

Figure 4.- Effect of deflection of the single slotted and double slotted flaps on the lift characteristics of the wing-fuselage combination equipped with 0.475b/2 leading-edge flaps.

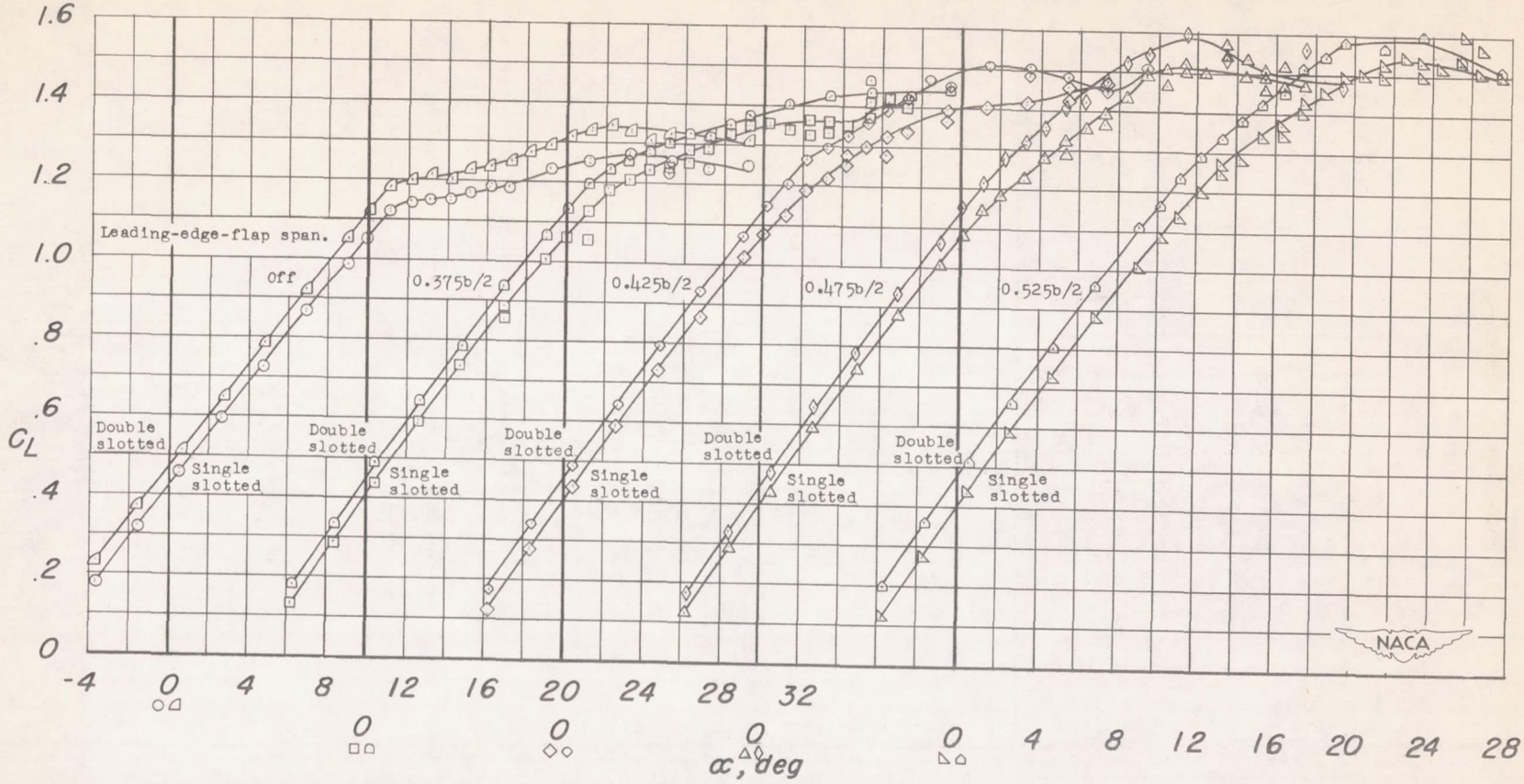
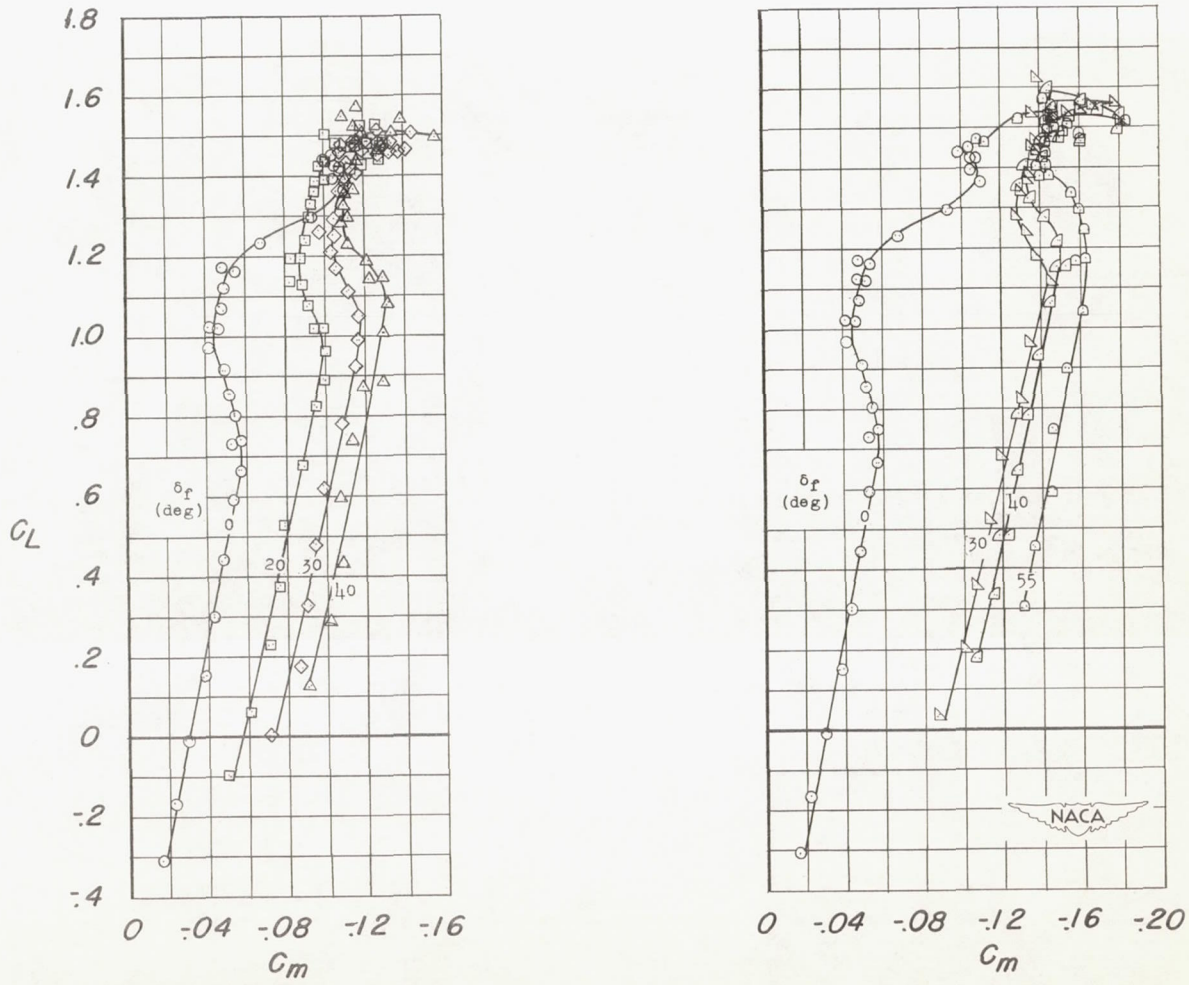


Figure 5.- Effect of leading-edge-flap span on the lift characteristics of the wing-fuselage combination equipped with the single slotted and double slotted flaps deflected 40°.



(a) Single slotted flaps.

(b) Double slotted flaps.

Figure 6.- Effect of deflection of the single slotted and double slotted flaps on the pitching-moment characteristics of the wing-fuselage combination equipped with 0.475b/2 leading-edge flaps.

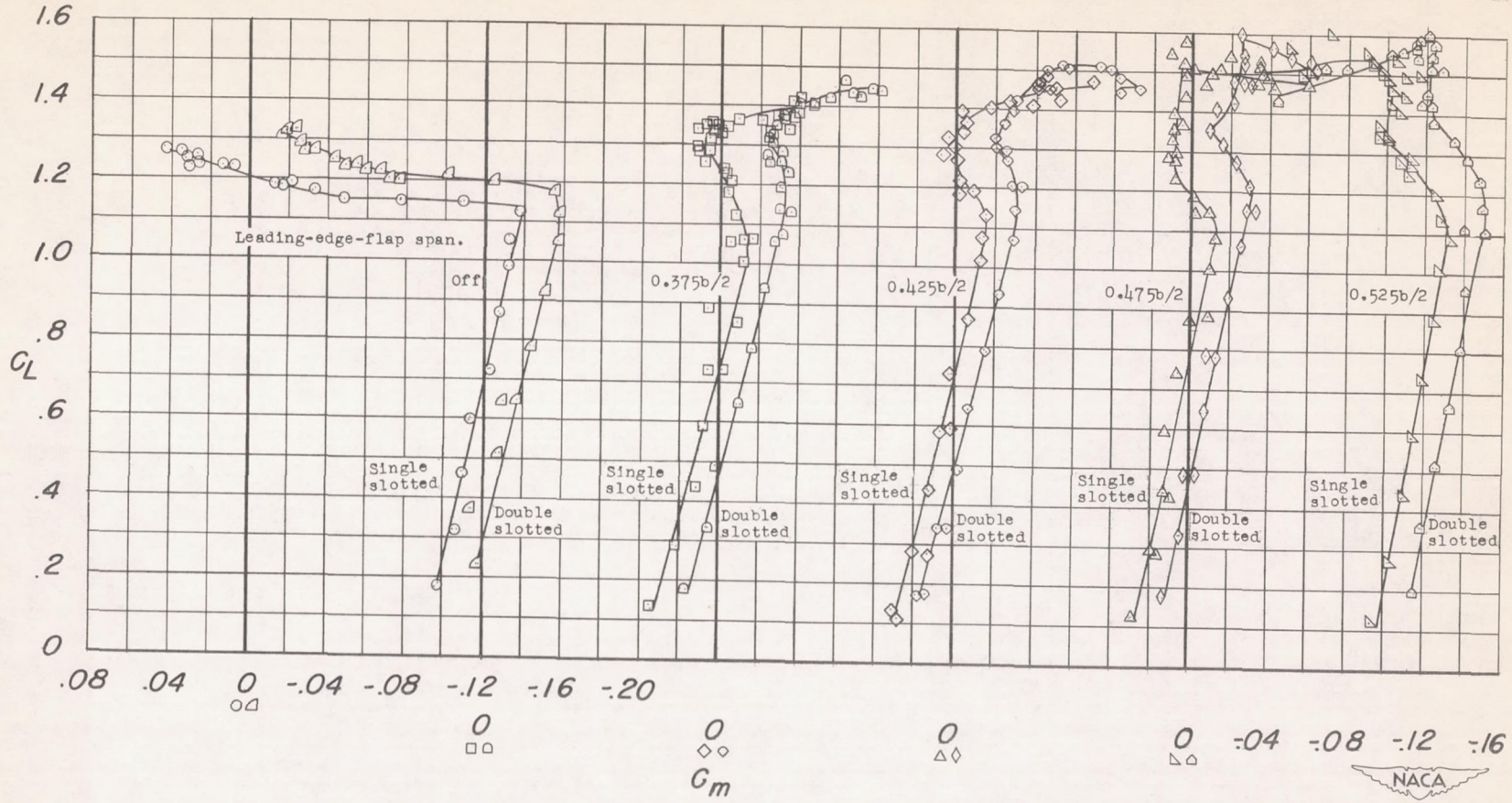
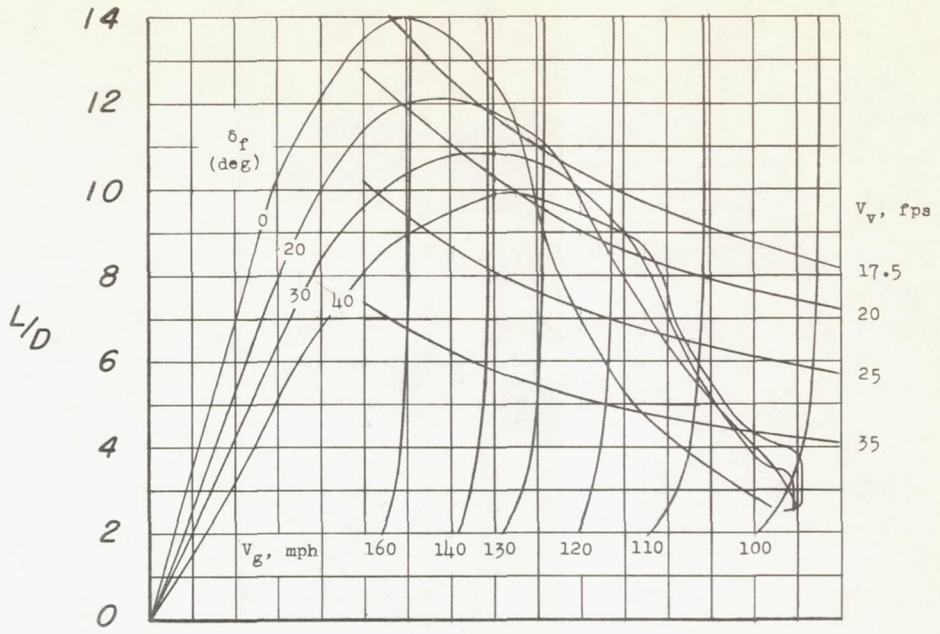
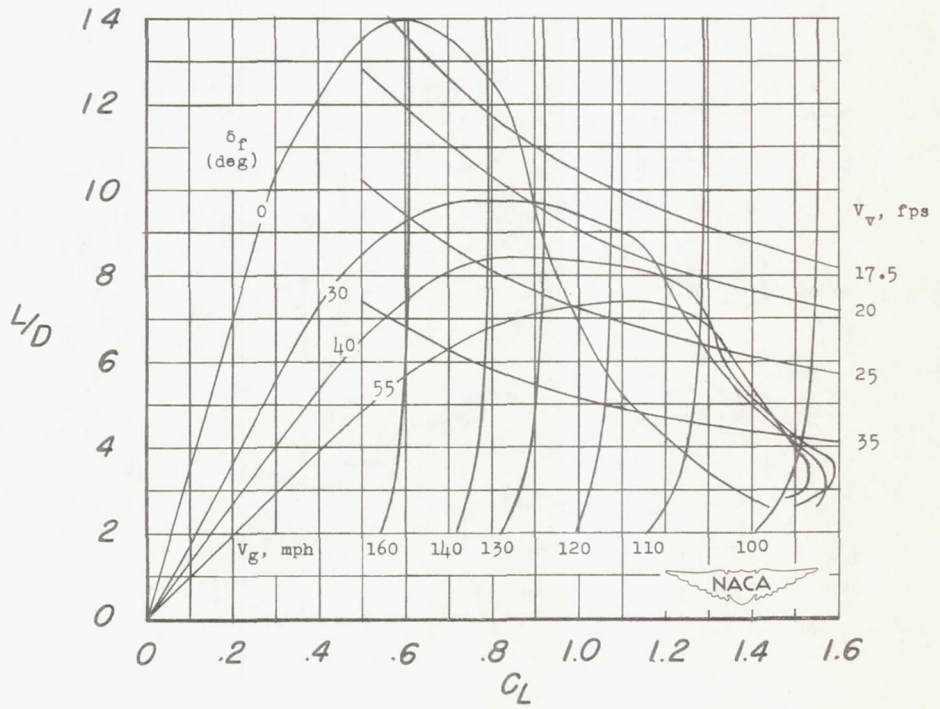


Figure 7.- Effect of leading-edge-flap span on the pitching-moment characteristics of the wing-fuselage combination equipped with the single slotted and double slotted flaps deflected 40°.

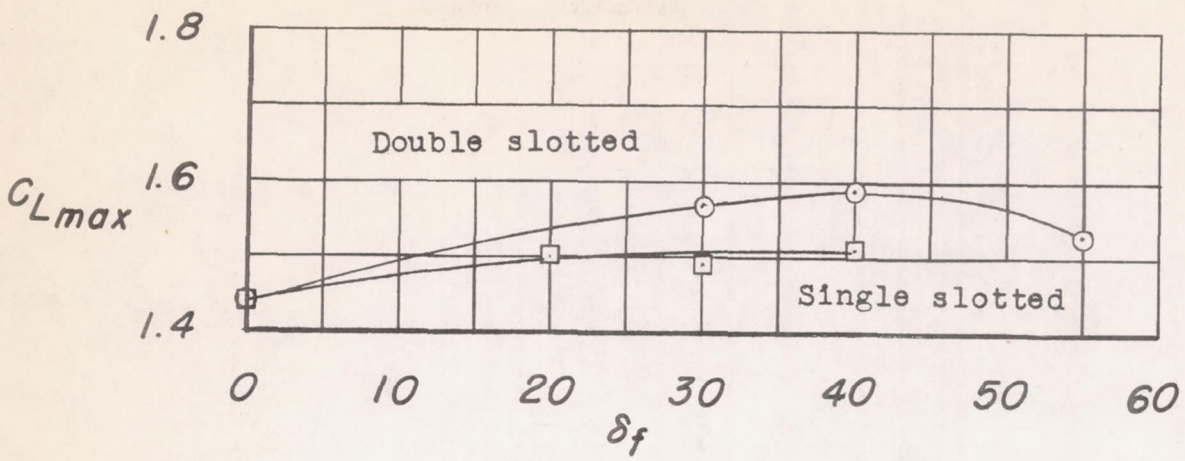


(a) Single slotted flap.

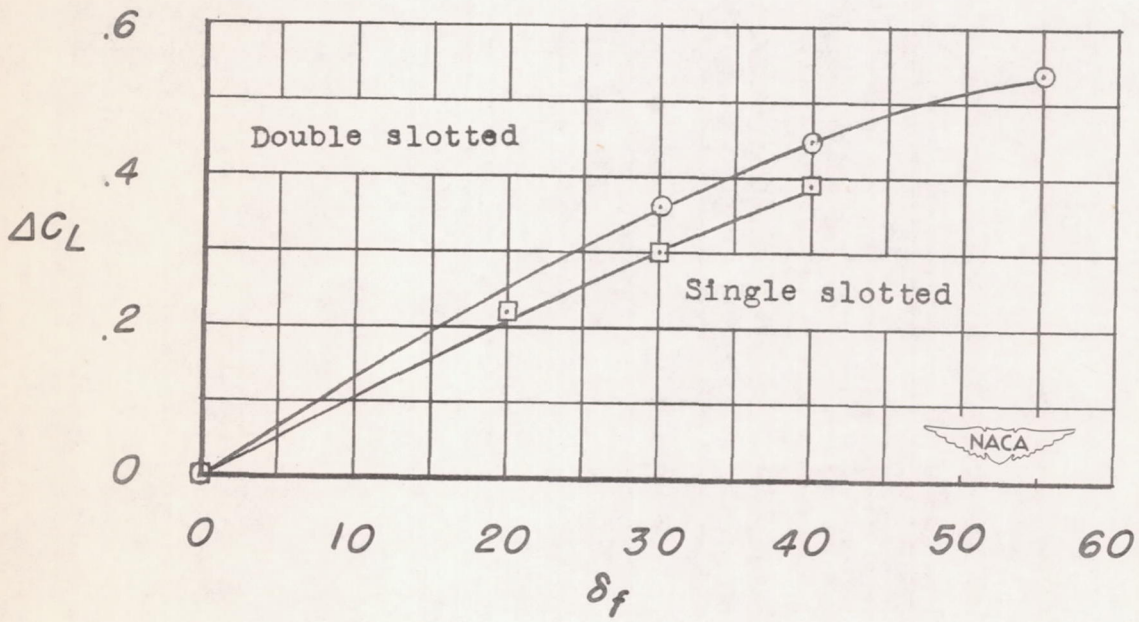


(b) Double slotted flap.

Figure 8.- Effect of deflection of the single slotted and double slotted flaps on the lift-drag ratios and glide characteristics of the wing-fuselage combination equipped with 0.475b/2 leading-edge flaps. Assumed wing loading of 40 pounds per square foot, sea-level conditions.



(a) $C_{L_{max}}$ against δ_f.



(b) ΔC_L against δ_f.

Figure 9.- Variation of $C_{L_{max}}$ and ΔC_L with deflection of the single slotted and double slotted flaps on the wing-fuselage combination equipped with 0.475b/2 leading-edge flaps.

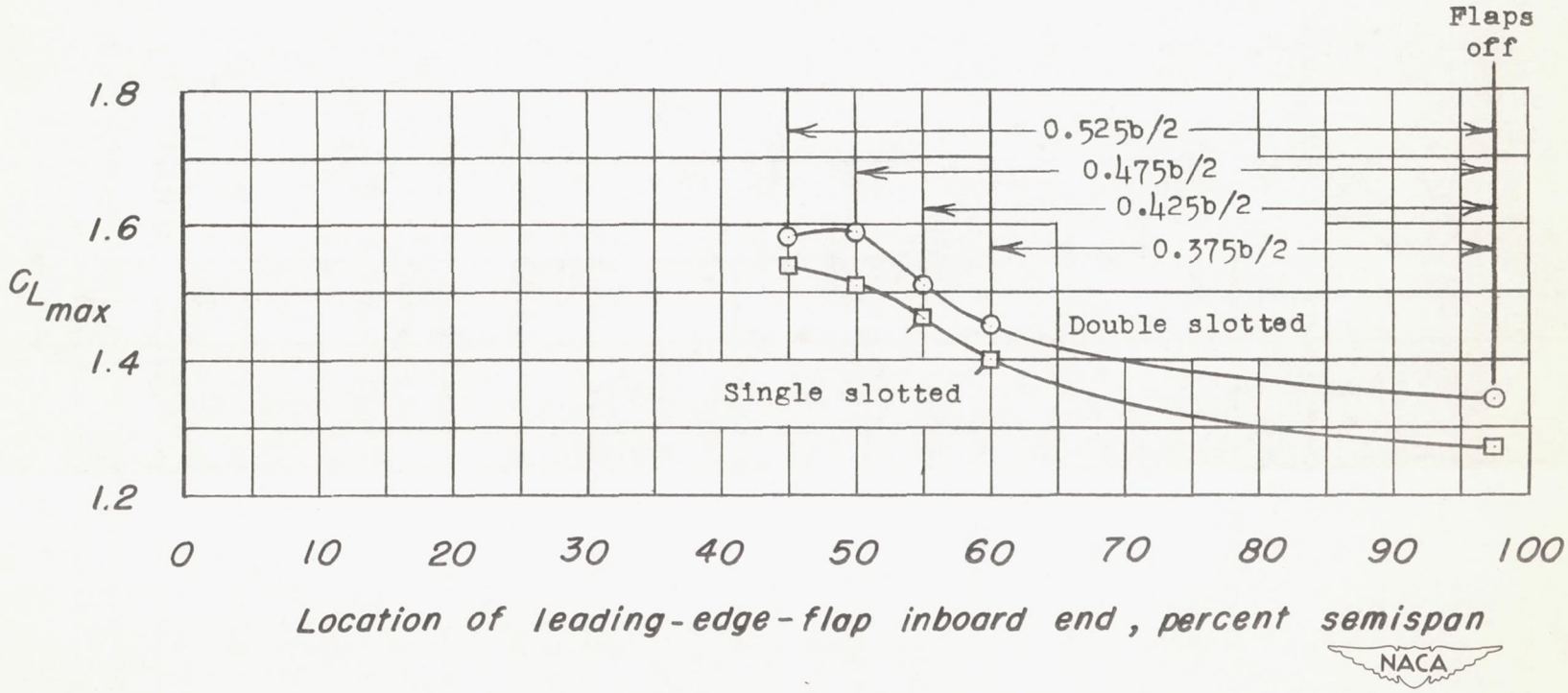


Figure 10.- Variation of $C_{L_{max}}$ with leading-edge-flap span for the wing-fuselage combination equipped with the single slotted and double slotted flaps deflected 40°. Flagged symbols indicate that C_L is increasing at highest α tested.

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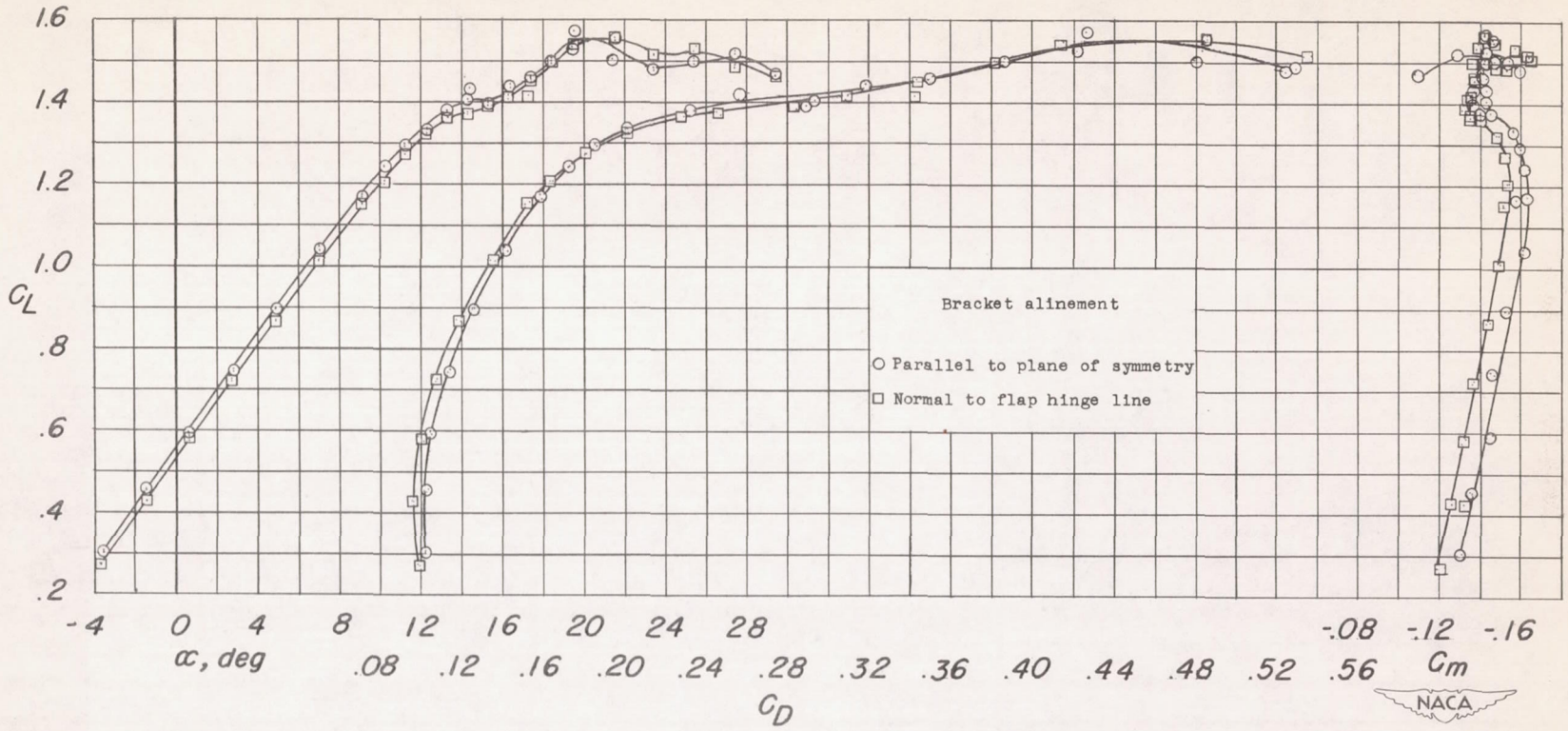

Figure 11.- Effect of alinement of the trailing-edge-flap brackets on the aerodynamic characteristics of the wing-fuselage combination. Double slotted flaps deflected 55°; 0.475b/2 leading-edge flaps.